

The Role of TiO₂ Nanoparticles in Enhancing the Structural Properties and Thermal Stability of PVA Nanocomposites

R.Venugopal¹, Chandana.N², S.Kiran³, B.Sreenivas⁴

Assistant Professor, Kakatiya Government College(A), Hanumakonda, Hanumakonda(Dist.), Telangana, India^{1,3}

Associate Professor, Government Degree College, Maheswaran, Rangareddy (Dist.), Telangana, India²

Assistant Professor, SR & BGNR Govt. Arts & Science College(A), Khammam, Khammam (Dist.), Telangana, India⁴

Abstract : Polyvinyl alcohol (PVA) nanocomposites reinforced with titanium dioxide (TiO₂) nanoparticles have garnered significant attention due to their unique properties and potential applications. In this study, we investigated the impact of TiO₂ incorporation on the structural characteristics and thermal stability of PVA-matrix-based nanocomposites. The PVA polymer nanocomposite films were prepared using a solution casting method. The structural studies of the prepared films were characterized via X-ray diffraction (XRD), transmission electron microscopy (TEM). Moreover, the thermal properties of the prepared films were characterized by DSC, TGA and DTA. The addition of TiO₂ nanoparticles induces structural changes in the PVA matrix. TEM studies showed that a PVA polymer surrounds TiO₂ in its entirety. The PVA-TiO₂ nanostructure is the same as the structure of a core-shell nanostructure. TiO₂-doped PVA nanocomposites exhibited improved thermal stability. Thermogravimetric analysis of the nanocomposite films demonstrated enhanced resistance to thermal degradation. DSC analysis of the PVA-TiO₂ nanocomposite films revealed that the glass transition temperature (T_g) and melting temperature (T_m) were 141°C and 265°C, respectively, for the 8 wt.% TiO₂-incorporated PVA-TiO₂ nanocomposites. The TGA and DTA studies of these nanocomposites revealed that their degradation behavior follows a four-step process. In comparison to those of pure PVA, these composites exhibit a sluggish decomposition rate, suggesting that the better thermal stability of these composites can be attributed to the better interaction among the -OH functional groups of PVA and TiO₂ nanoparticles. These nanocomposites hold promise for various applications, including coatings, sensors, and optoelectronic devices. The combined effects of structural reinforcement and thermal stability make these materials attractive for engineering applications.

Index Terms- Solution casting, PVA-TiO₂ nanocomposites, XRD, TEM and Thermal properties.

I. INTRODUCTION

Polyvinyl alcohol (PVA) is a synthetic polymer that is water soluble and biodegradable, making it environmentally friendly. It has excellent film-forming properties, high tensile strength, and flexibility, making it a versatile material for various applications[1]. PVA is commonly used in industries such as packaging, textiles, adhesives, and pharmaceuticals[2]. In research, PVA is often explored for its potential in creating nanocomposites by incorporating nanoparticles to enhance its properties, such as its mechanical strength, thermal stability, and barrier properties. Studying the structure-property relationships of PVA nanocomposites can provide valuable insights for developing advanced materials with tailored characteristics for specific applications.

PVA nanocomposites are of significant importance in diverse industries owing to their superior characteristics in comparison to those of pure PVA[3]. These composite materials offer numerous benefits, rendering them crucial for a variety of uses[4]. Enhanced strength, toughness, and durability are exhibited by PVA nanocomposites, thus rendering them appropriate for applications where mechanical strength is indispensable, such as in packaging materials necessitating resistance to tearing or puncturing[5,6]. The incorporation of nanoparticles into PVA has the potential to enhance the thermal stability and increase the resistance to elevated temperatures[7]. Consequently, PVA nanocomposites are of considerable value for industries where thermal efficiency is of utmost importance, for instance, in electronics where heat dissipation is a critical factor[8]. Compared with pure PVA, PVA nanocomposites can enhance barrier properties against gases, moisture, and other environmental

elements[9]. Therefore, they are well suited for applications in packaging to extend the shelf life of products or in biomedical devices to prevent contamination. Owing to their superior characteristics, PVA nanocomposites are utilized in various industries, such as the packaging, biomedical, and electronics industries. These materials can be customized to fulfil the specific demands of different sectors, making them versatile and highly valuable.

The incorporation of metal oxide nanoparticles into PVA nanocomposites enhances their properties for various applications[10]. Magnesium oxide or zinc oxide can significantly improve the mechanical properties of PVA nanocomposites. This enhancement makes them suitable for durable applications. Metal oxide nanoparticles enhance the thermal stability of PVA nanocomposites, which is crucial for high-temperature applications. They also improve barrier properties, making them effective at blocking gases and moisture[11]. Some metal oxide nanoparticles, such as silver nanoparticles, have antimicrobial properties that can be incorporated into PVA nanocomposites for biomedical or food packaging use[12]. Metal oxide nanoparticles offer unique optical properties when added to PVA nanocomposites and are suitable for UV-protective coatings or self-cleaning surfaces[13]. Graphene oxide or indium tin oxide nanoparticles can provide electrical conductivity to PVA nanocomposites, which is essential for electronics and conductive coatings[14,15].

On the other hand, titanium dioxide (TiO_2) is a widely used nanoparticle due to its unique properties, such as high stability, low toxicity, and excellent photocatalytic activity[16]. TiO_2 nanoparticles have a wide range of applications in various fields, including cosmetics, food additives, environmental remediation, and biomedical applications[17]. TiO_2 is often studied for its ability to enhance the structural properties, thermal stability, and other characteristics of nanocomposites when incorporated into polymer matrices[18]. The interactions between TiO_2 nanoparticles and the polymer matrix may play a crucial role in determining the overall properties of the nanocomposites, making TiO_2 a valuable material for nanotechnology research and applications[19].

Enhancing the structural characteristics and thermal stability of PVA-based materials remains a significant challenge. One promising approach to address this issue is the incorporation of inorganic nanoparticles, such as titanium dioxide (TiO_2), into the PVA matrix to create nanocomposites with improved properties. The interaction between PVA and TiO_2 nanoparticles has been reported to influence the structural, mechanical, and thermal properties of the resulting nanocomposites. In this study, we investigated the impact of TiO_2 nanoparticles on the structural properties and thermal stability of PVA nanocomposites to understand the underlying

mechanisms and potential applications of these materials. Studying the impact of TiO_2 nanoparticles on PVA nanocomposites is essential for advancing the field of nanocomposite materials, developing innovative applications, and gaining insights into the structure-property relationships that govern the behavior of these advanced materials.

II. MATERIALS

Polyvinyl alcohol (PVA) with a molecular weight (M.W.) ranging from 85,000 to 1,24,000 g/mol was acquired from SD. fine Chem Ltd., India. Titanium dioxide (TiO_2) nanoparticles were purchased from Ad-Nano Technologies Pvt. Ltd., India. The purity of TiO_2 is reported to be 99.9%, with an average particle size ranging from 30-80 nm. The specific surface area (SSA) of the TiO_2 NPs was $150 \text{ m}^2/\text{g}$, and the bulk density was 0.35 g/cm^3 . TiO_2 has a molecular weight of 233.8 g/mol and a melting point of 1580°C . Nanosized TiO_2 particles existed in the anatase phase according to JCPDS card no. 21-1272. In its physical state, the material exists as a white powder with a spherical morphology.

Preparation of PVA- TiO_2 Nanocomposites

A solution casting approach was employed to develop PVA- TiO_2 NC films. Fig.1 shows the diagrammatic procedure for the preparation of PVA- TiO_2 NC films. PVA (5.0 g) in wt. was dissolved in 80 ml of double-distilled water. After stirring vigorously for nine hours, 2 wt.% of the nanosized TiO_2 was dispersed in 20 ml of double-distilled water. The obtained liquids were mixed and stirred for 24 hours to ensure a uniform dispersion of TiO_2 NPs in the polymer matrix. The viscous gel obtained after this process was poured into Petri dishes made of polypropylene. As shown in Fig.1, the gel was allowed to remain at ambient temperature until it was completely dry. This process resulted in a nanocomposite film without bubbles. Peeling the film from the Petri dish yielded a PVA- TiO_2 nanocomposite film. A similar procedure was repeated to prepare PVA- TiO_2 nanocomposites with 4, 6, and 8 weight percent TiO_2 nanoparticles.

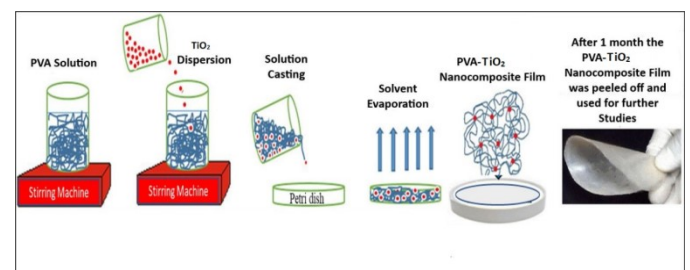


Fig.1. Schematic procedure for the preparation of PVA- TiO_2 NC films.

Characterization Techniques

The PVA- TiO_2 NC films were assessed for their structural characteristics by utilizing a SHIMADZU XRD-7000 diffractometer equipped with a Cu ($K\alpha$) source operating at a

wavelength of 1.5406 Å. The samples were coated with a 3.5 nm gold layer to reduce the charging effects of the electron beam. ZnS NPs shape, size, and distribution in PVA were studied using a transmission electron microscope (FEI Tecnai S-Twin 200kV). The DSC curve covers the temperature range of 20°C-400°C at 50 ml/min in a nitrogen atmosphere with a 10°C /min heating rate. The TGA thermograms of PVA nanocomposites were recorded using a thermogravimetric analyzer (Perkin Elmer STA-6000) at a heating rate of 10°C /min in an inert nitrogen atmosphere. The DTA thermograms of the polymer film were simultaneously recorded using the same instrument.

III. RESULTS AND DISCUSSIONS

XRD Analysis

Fig.2 presents the XRD results for PVA-TiO₂ complexation with different TiO₂ compositions (0, 2, 4, 6, and 8 wt.%). The XRD spectrum of pure PVA demonstrates a moderately broad characteristic peak at 2θ ~19.70° due to its amorphous nature. The incorporation of TiO₂ into the PVA matrix caused a shift in the diffraction peak to 19.79°, 19.82°, 19.83°, and 19.98° for the various PVA-TiO₂ nanocomposite systems. Additionally, a small but sharp anatase TiO₂ (JCPDS Card No. 21-1272) peak at 2θ=25.56° appears in the XRD patterns of the prepared films.

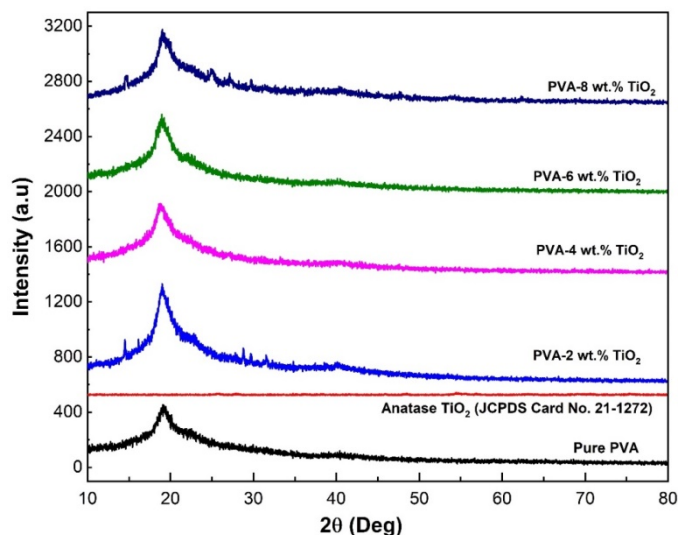


Fig.2. XRD spectra of pristine and TiO₂-doped PVA films.

The uniform dispersion of TiO₂ NPs within the PVA matrix was determined by analysing the equivalent peak positions found in all the NC films [20]. The successful production of PVA NC films with increased strength and a slightly modified amorphous structure, which can be attributed to the inclusion of TiO₂, further reinforces this discovery. The presence of multiple hydroxyl groups on the PVA backbone prevents any structural modifications when TiO₂ nanoparticles are added

[21]. The incorporation of TiO₂ nanoparticles into PVA causes a reduction in the spacing between PVA chains, leading to a decrease in the amorphous nature of PVA. The XRD peak intensity in the diffractograms also increases as the TiO₂ concentration in the nanocomposite films increases. Furthermore, the width of the XRD peaks shows a moderate increase with increasing TiO₂ concentration in the films.

Transmission Electron Microscopy (TEM) Studies

TEM helps in characterizing nanomaterials. The particle size and distribution were quantified. The resolution of TEM is greater than that of SEM. TEM can be used for analysis and has better spatial resolution than SEM. The use of a high vacuum, tiny sample slice, and time-consuming sample preparation are limitations of this approach. Sample preparation is crucial for extracting information from a high-quality image [22].

HR-TEM Imaging of PVA-TiO₂ Nanocomposite Films

Transmission electron microscopy (TEM) was utilized to characterize the shape of the nanoparticles distributed in the PVA-TiO₂ NCs, and the nanoparticle size was determined. A transmission electron micrograph of PVA that was incorporated with 6% TiO₂ by weight is shown in Fig.3. One can observe that there is a PVA chain surrounding the TiO₂ in its entirety. The PVA-TiO₂ nanostructure is the same as the structure of a core-shell nanostructure, which is an intriguing component of the TEM image [23].

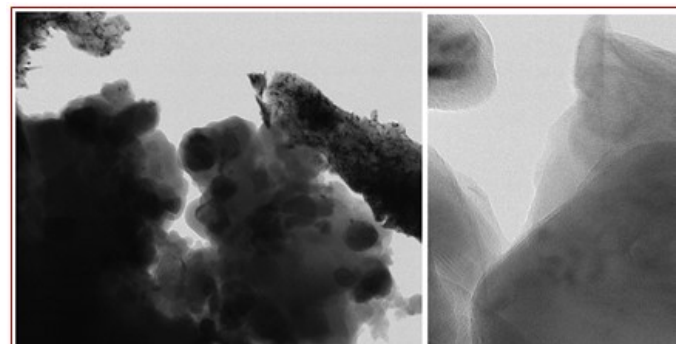


Fig.3. HR-TEM micrograph of PVA-8 wt.% TiO₂ nanocomposite films

TiO₂ nanoparticles work as the core, and PVA acts as the shell for these nanostructures. These core-shell nanostructures possess potential application viability. Hence, these materials have become valuable raw materials for the production of sensors. Following the conclusion of the oxidative polymerization process, a PVA layer is produced on top of the TiO₂ nanostructure. As a consequence of this step, a tubular nanostructure is formed [24].

Selected Area Electron Diffraction (SAED) Analysis

SAED analysis is utilized for study the materials because it is easy to use and provides a large amount of information. After

the sample was prepared and examined with a modern transmission electron microscope, the instrument was used for standard diffraction acquisition in seconds. The SAED test determines whether a substance is crystalline or amorphous by nature. SAED measurements were performed with the help of a transmission electron microscope. If they are studied correctly, images can be used to find crystal structures, estimate crystal orientations, measure crystal features, look at crystal defects, and judge the textures of materials. The analysis depends on the sample being examined and how the diffractogram is analysed.

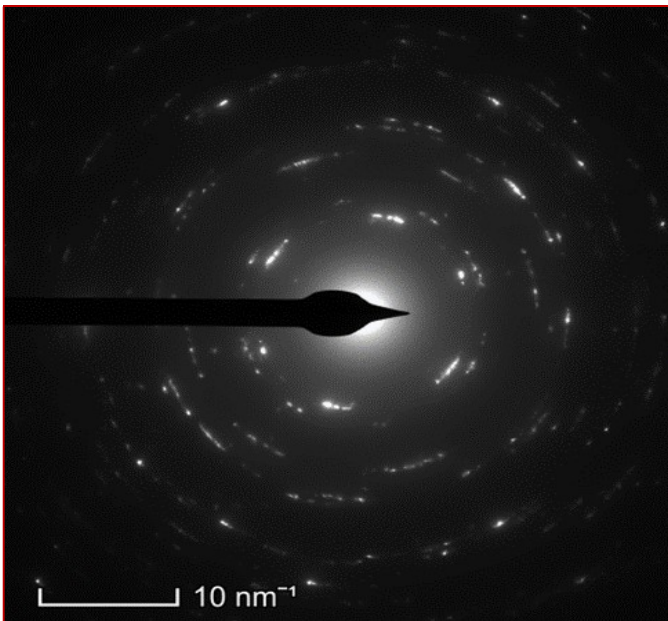


Fig.4. Selected area electron diffraction pattern of the PVA-8 wt.% TiO₂ nanocomposite films

Fig.4 shows the SAED patterns obtained for the PVA-8 wt.% TiO₂ composite material. Against a dark background, these patterns make it clear that there are dazzling white spots distributed in several different circular orbits. The SAED pattern for amorphous materials does not have any bright spots in the image, as was previously reported; rather, only circular rings are observed in the pattern. On the other hand, the image of the SAED pattern for crystalline materials will have brilliant spots in addition to circular orbits. In this research on PVA-TiO₂ nanocomposites, the SAED patterns indisputably showed the presence of bright spots, proving that the composite has a semicrystalline structure. The X-ray diffractograms of these nanocomposites do not show any highly intense crystalline peaks because the composite materials have localized crystalline structures, which cannot be observed via XRD but rather through highly sophisticated TEM.

Differential Scanning Calorimetry (DSC) Studies

The manifestation of endothermic peaks in all the curves is indicative of the glass transition in all the samples. Detailed recordings of the observed glass transition (T_g), melting (T_m) and degradation (T_d) temperatures can be found in Table 1. The pure PVA sample has lower T_g and T_m values than the composites.

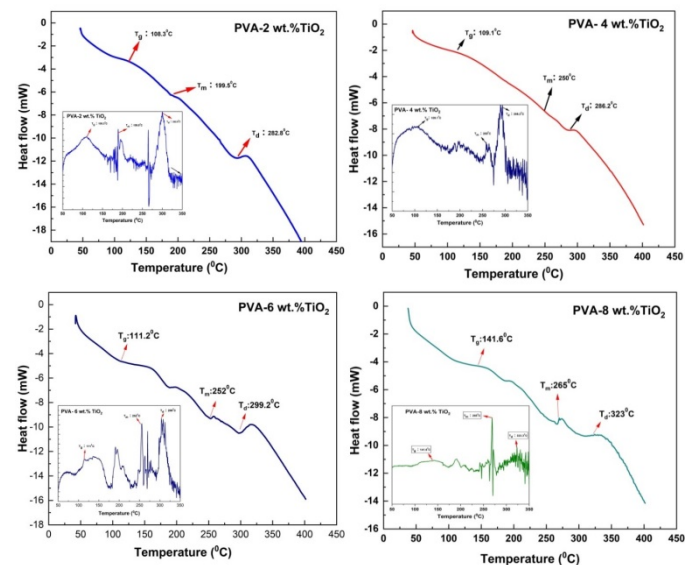


Fig. 5. DSC thermograms of the PVA and PVA-TiO₂ nanocomposites.

The results showed that the T_g values of the PVA-TiO₂ nanocomposites increased with increasing TiO₂ concentration[25]. It is important to note that the increased probability of nanoparticle agglomeration accounts for the increase in the magnitudes of all the degradation characteristic temperatures with increasing TiO₂ wt.% of the nanocomposites. The agglomeration process leads to the conversion of the nanostructure of TiO₂ particles to a microstructure, resulting in a positive impact on the thermal stability of the nanocomposites. Consequently, macromolecular chains are more prone to breakdown due to heat, as the dispersed nanoparticles exhibit extended efficacy in their protective role, particularly when compared to samples with a lower wt.%.

A monotonic trend is shown in Fig.5. The observations indicated that the T_g of the PVA-TiO₂ nanocomposites exhibited a notable trend with increasing wt.% TiO₂ in the nanocomposite films. This is because of the many factors that affect the polymer chain's degree of freedom [26]. In most nanocomposites, two primary elements compete with one another. One of the primary elements is coated as an existing organic layer, which would be a polymer, in the present case, around the nanoparticles. An increase in the degree of freedom and entropy of composite systems results in a decrease in the T_g value. The inclusion of inorganic NPs

within the polymer matrix lowers the density of the configuration states of macromolecules. Consequently, the disorientation entropy decreases, leading to a growth in the T_g value. Notably, however, the aggregation of NPs, the shape of the NPs, and the order of film uniformity may vary across different samples.

Table 1. Glass transition temperature (T_g), melting point (T_m), and decomposition temperature (T_d) of the PVA- TiO_2 composite films

S.No	Sample	T_g (°C)	T_m (°C)	T_d (°C)
1	PVA	104.3	193.2	255
2	PVA - 2 wt. % TiO_2	108.3	199.5	282.8
3	PVA - 4 wt. % TiO_2	109.1	250	286.2
4	PVA - 6 wt. % TiO_2	111.2	252	299.2
5	PVA - 8 wt. % TiO_2	141.6	265	323

Fig.5 also displays endothermic peaks at approximately 193-265°C in all the samples, which are apparent indications of the decomposition of the PVA- TiO_2 nanocomposite films. Additionally, minor endothermic peaks were identified at low temperatures near 100°C. Water vapour exhibits these endothermic peaks at this temperature[27]. In addition to the core endothermic peaks, no additional noticeable thermal peaks were identified. This result coincided with the T_g measurements, indicating that degradation occurred in three steps and validating the creation of very thermally stable nanocomposites.

Thermogravimetric Analysis (TGA)

The thermal stability of the PVA- TiO_2 nanocomposite films was assessed via TG analysis. Fig.6 displays the TG curves, which were compared to those of the parent PVA for reference purposes. These data show four transition temperatures where degradation processes occur[28]. These characteristic temperatures and residual weight percentages are presented in Table 2.

Dewatering temperature: Water molecules are eliminated at higher temperatures in the PVA- TiO_2 nanocomposite films than in the pristine PVA, which is indicated by the increase in dewatering temperature ($T_{d,w}$) [Table 2].

The $T_{d,w}$ of pristine PVA is significantly shifted from 103°C to 112°C (for 8 wt.% TiO_2) by the progressive addition of TiO_2 nanomaterials. The values of $T_{d,w}$ show that the degree of absorbed water in the PVA matrix depends on the composition of all the samples. This result is supported by DSC analysis.

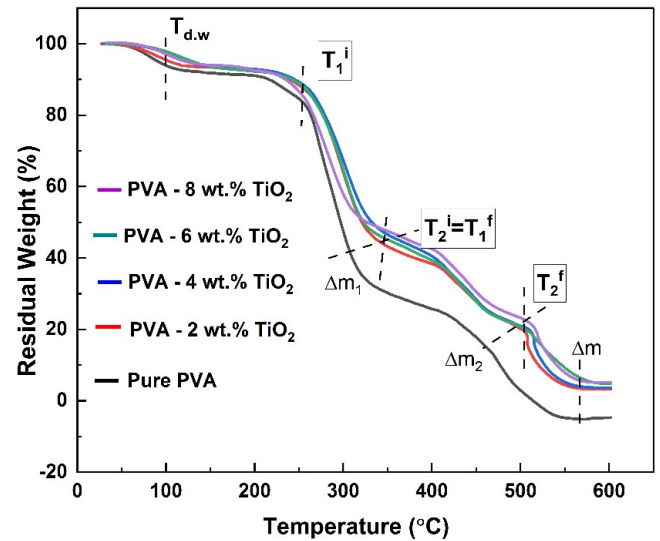


Fig.6 TG curves of the PVA- TiO_2 nanocomposites

First degradation step: Onset decomposition is noted as the initial degradation temperature (T_{1i}). Peng et al. [29] reported that elimination and chain scission reactions occur in parallel at this stage. Table 2 shows that the initial degradation temperature (T_{1i}) of the nanocomposite is slightly greater than that of the pristine PVA matrix.

The first initial degradation temperature of PVA (i.e., 198°C) is shifted to a higher temperature of approximately 250-265°C in the PVA- TiO_2 nanocomposite films, which is attributed to degradation of the polymer matrices by the barrier effect of the TiO_2 nanomaterials[30]. The introduction of TiO_2 nanomaterials into nanocomposite systems has been found to have a dualistic impact on the thermal stability of the materials. On the one hand, TiO_2 nanomaterials exhibit a barrier effect, which leads to an overall increase in thermal stability. Conversely, they also display a catalytic effect on the degradation of the polymer, which leads to a decrease in the thermal stability. This suggests that the first degradation temperature of the composite films shifts early to higher temperatures, ranging from 198°C for 2 wt.% TiO_2 to 265°C for 8 wt.% TiO_2 . This phenomenon can be attributed to the reduced mobility of the PVA chains in the nanocomposite. The reduced mobility of the PVA chain is caused by two effects. First, the catalytic effect of TiO_2 nanomaterials causes the PVA matrix backbone to be more rigid by creating C=C double bonds. Second, the Ti^{2+} of TiO_2 is involved in complex formation with the -OH functional groups of the PVA matrix. Hence, the barrier effect and complex formation effect increase the onset degradation temperature of the nanocomposite.

Second degradation step: At the second degradation temperature (T_{2i}), chain scission and cyclization reactions occur. In the present investigation, the T_{2i} value of the

nanocomposite shifted to a lower temperature of approximately 328-353°C from 318°C for the pristine PVA matrix, which is ascribed to the catalytic effect of TiO₂ nanomaterials in the process of generating polyaromatic structures.

Weight residue: Carbonized residue formed between 510°C and 560°C. At this stage, the weight loss of the nanocomposite is less than that of the parent PVA.

Table 2. Thermal analysis of the PVA-TiO₂ nanocomposite films

Sample code	T _{d,w} (°C)	T _{1ⁱ} (°C)	T _{2ⁱ} (°C)	Δm ₁ (%) at T _{1^f}	Δm ₂ (%) at T _{2^f}	Δm (%) at 600 °C
Pristine PVA	103	190	380	42.6	33.5	2.8
PVA-2 wt.% TiO ₂	108	204	353	46.2	28	3.2
PVA-4 wt.% TiO ₂	109	208	330	42.3	25.5	3.6
PVA-6 wt.% TiO ₂	110	210	328	44.0	23.8	4.8
PVA-8 wt.% TiO ₂	112	215	327	41.99	28	5.2

- (T_{1i}, T_{2i}) – Onset temperature of decomposition for the first and second steps of degradation according to the TGA curve.
- Δm_{1,2} - mass loss at the end of the first (T_{1f}) and second (T_{2f}) step of degradation from the TGA curve.
- Δm – mass loss at 600°C

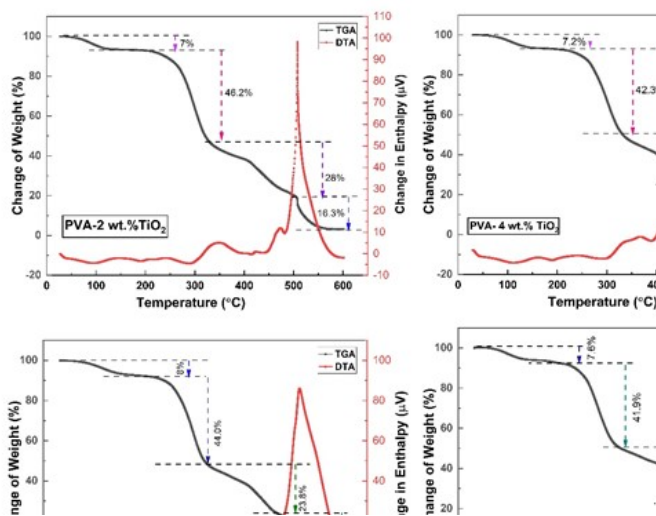


Fig.7 TGA and corresponding DTA plots of the PVA-TiO₂ composite films with different concentrations of TiO₂ NPs.

The weight loss percentage for the PVA-TiO₂ nanocomposite at 600°C is shown in Fig.7. The wt. loss % of all the PVA-TiO₂ nanocomposite films studied was greater than that of the parent PVA, as illustrated in Fig.7. It seems that the greater chain confinement due to better interactions with even small amounts (i.e., 2 wt. %) of TiO₂ nanomaterials controls degradation via a charge transfer reaction. The residual weight at 600°C for 8 wt. % of the PVA-TiO₂ nanocomposite is approximately 6.2%, which is higher than that of the parent PVA matrix residual weight (i.e., 0.3 %) [Table3]. This finding suggested that the introduction of TiO₂ nanomaterials into PVA polymers influences their thermal degradation.

Table 3. Degradation steps, wt. loss% and temperature. at the largest wt. loss rate (T_m) of the PVA-TiO₂ nanocomposites according to the TGA/DTA plots

Sample	Temperature Range(°C)	Temp. @ largest wt. loss rate (T _m) (°C)	Weight Loss (%) Partial	Weight Loss (%) Total
PVA	49-190	103	7.4	99.7
	190-380	271	45.7	
	380-474	399	34.6	
	474-600	473	12	
PVA - 2 wt.% TiO ₂	47-203	108	7	96.8
	203-352	287	46.2	
	352-511	347	28	
	511-600	521	16.2	
PVA - 4 wt.% TiO ₂	47-208	109	7.2	96.3
	208-330	238	42.3	
	330-461	444	25.5	
	461-600	512	21.4	
PVA - 6 wt.% TiO ₂	47-210	110	8	95.2
	210-328	261	44	
	328-482	437	23.8	
	482-600	514	19.2	
PVA - 8 wt.% TiO ₂	47-215	112	7.6	94.8
	215-328	274	41.9	
	328-504	420	28	
	504-600	519	17.1	

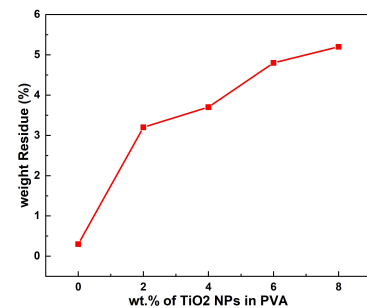


Fig.8 Effect of the TiO₂ NPs on the PVA-TiO₂ nanocomposite weight residue at 600°C.

Thermogravimetric analysis (TGA) revealed that the initiation of thermal decomposition and the formation of carbonaceous materials in the PVA-TiO₂ nanocomposite occurred at higher

temperatures than those in the parent PVA. The incorporation of TiO₂ as a catalyst also facilitates the onset of thermal decomposition and the formation of carbonaceous materials, which is supported in the present investigation.

Differential thermal analysis (DTA)

The impact of TiO₂ NP incorporation on the thermal stability of PVA was explored through DTA. DTA plots of the PVA-TiO₂ composites is shown in Fig.9. The TGA plot of PVA (Fig.7) revealed that its degradation behavior followed a four-step process.

The first degradation step resulted in a minor wt. loss (approximately 7%) assigned to the loss of water content from the prepared film as well as the breakdown of small molecules in the PVA sample. The second degradation step from 190-380°C resulted in significant weight loss (up to 46.2%). The third degradation step (380°C -474°C) involved weight loss (up to 16.3%), possibly due to the melting point (T_m), decomposition temperature (T_d), and bond scissoring of the homopolymers [29].

The fourth degradation step (474°C -600°C) corresponded to a 9-20% wt. loss and may be due to the complete degradation of large-molecule wt. products such as the acetate group. The chain-scission reactions mainly governed this degradation step when the temperature was high enough to break the high-molecular-weight wt. products. These observations are consistent with the reported literature [31, 32].

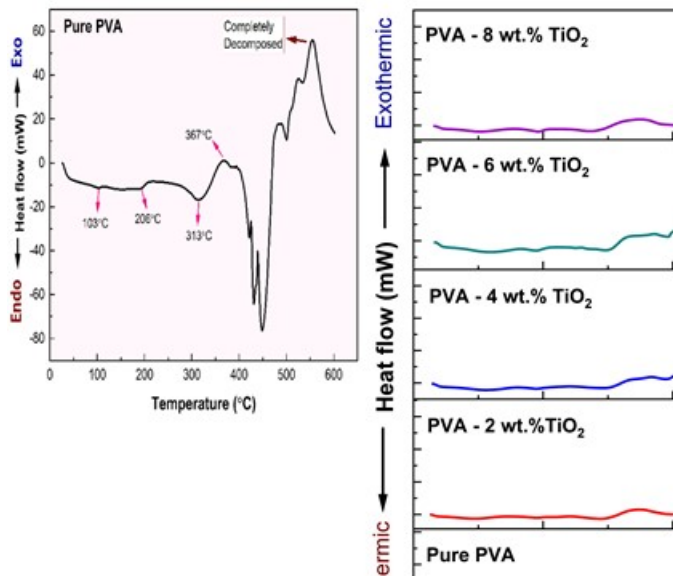


Fig.9. DTA thermograms of the PVA and PVA-TiO₂ composite films

Table 4. T_g, T_m, T_d and complete degradation temperature (T_{d2}) of PVA-TiO₂ nanocomposites obtained by DTA.

Sample	1 st endothermic peak (T _g °C)	2 nd endothermic peak (T _m °C)	3 rd endothermic peak (T _{d1} °C)	4 th exothermic peak (T _{d2} °C)
Pure PVA	103	206	313	367
PVA-2 wt.% TiO ₂	108	218	273	496
PVA-4 wt.% TiO ₂	109	216	269	475
PVA-6 wt.% TiO ₂	110	216	259	465
PVA-8 wt.% TiO ₂	112	219	260	460

The four-step degradation behavior of PVA was confirmed by the corresponding four peaks in its DTA plot (Fig.9). Fig.9 shows the DTA plots of the PVA- TiO₂ composites with 2, 4, 6 and 8 wt.% TiO₂ NPs in PVA. The thermal degradation of the composites also involved a four-step process, as observed from the TGA and corresponding DTA plots of all the PVA-TiO₂ composite samples, similar to those of PVA. As the wt. % TiO₂ concentration increased in the nanocomposites, the peak position of the fourth degradation step in the DTA curve gradually moved to a higher temperature. The observed shift in the DTA peak toward higher temperatures confirmed the enhanced thermal stability exhibited by the composites in comparison to that of pure PVA. Furthermore, it was evident that both the weight loss and weight loss rate were greatest in the second degradation step. The DSC results were almost in good agreement with the TGA results. The degradation steps corresponding to temp. at the largest wt. loss rate (T_m) in the DTA plots, and the wt. loss percentages of the PVA-TiO₂ nanocomposites are listed in Table 3.

IV. CONCLUSION

TEM was used to determine the structure of the PVA-TiO₂ as well as the size of its particles. The structure of the PVA-TiO₂ is a core-shell nanostructure, with TiO₂ as the core and PVA as the shell. This structure is the same as that of a core-spherical-shell nanostructure. On top of the TiO₂ nanostructure, a PVA layer is made, and as a result, a spherical nanostructure is made. The SAED test was performed to determine whether the material was crystalline or amorphous in its natural state. The SAED patterns of the PVA-TiO₂ nanocomposites clearly showed bright spots, which indicated that the composite had a semicrystalline structure. DSC revealed that the glass transition temperature (T_g) and melting temperature (T_m) were approximately 141°C and 265°C, respectively, for the 8 wt.% TiO₂-incorporated PVA-TiO₂ nanocomposites. The TGA and DTA studies of these nanocomposites revealed that their degradation behaviour is a four-step process. In comparison to

pure PVA, these composites exhibit a sluggish decomposition rate, suggesting a better thermal stability that can be attributed to the better interaction among the -OH functional groups of PVA and TiO₂ nanoparticles.

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